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Integrated emergy and economic evaluation of three typical rocky desertification control modes in karst areas of Guizhou Province, China

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ABSTRACT

Guizhou Province of China is a key karst area and is facing serious rocky desertification. Controlling the rocky desertification in karst areas in Guizhou has been formally established as a national goal. After decades of experience, some control modes are now recognized for their ability to reduce desertification and to provide income for the local community. However, a unified, integrated ecological and economic evaluation of these modes is lacking. The current study evaluated three modes (planting systems) and compared these modes with the planting of corn (CP), a traditional crop in this region. The three typical modes were pepper planting (PP), pitaya cultivation (PC), and honeysuckle-plum inter-planting (HPIP). Furthermore, the ecological and economic effects of adding livestock and biogas subsystems to the PP mode were quantified. The results showed that the PP mode provided the highest ecological-economic benefits, while the HPIP mode provided the highest ecological benefits. The addition of the livestock subsystem to the PP mode could improve the economic benefit density of the system with a tradeoff of environmental loading, while the addition of the biogas subsystem could partially correct for this. We suggest that local governments to strength the technology support for these modes in order to expand the production chains; this will include the development of processing facilities for livestock, biogas, and crops. Local governments should also help farmers maintain markets, create new markets (by branding the products, for example), and establish a short-term labor supply for crop harvesting.
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1. Introduction

Rocky desertification transforms a karst area covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation (Yuan, 1997). It has occurred in karst areas in the Mediterranean basin (Yassoglou, 2000), the Dinaric Karst (Gams and Gabrovec, 1999), and southwest China (Yuan, 1997) because of the fragile ecological environments and human disturbance (Jiang et al., 2014). Rocky desertification can result in natural disasters such as landslips, debris flow, droughts, and floods that seriously affect the regional residents and hinder the coordinated development of the local society, economy, and ecology (Ren, 2005; Xiong and Chi, 2015).

Humans have long attempted to control rocky desertification in the fragile karst areas. In 1150 AD, for example, the government of Trieste, Italy restricted the cutting of trees for firewood and prohibited the breeding of goats (Ford and Williams, 2007); around 1250 years BP, Arabs used terrace farming and an irrigation-based sustainable agricultural system in the Mediterranean area (Yassoglou, 2000); and the establishment of olive groves with understory vegetation is considered one of the most land-protective

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systems in the Mediterranean region (Kosmas et al., 1996).

Research on the control of rocky desertification in China began in the 1980s, and some mode were developed, included the returning of farmland to forests and grassland, afforestation, and the preservation of hillsides for forest conservation (Cai and Lu, 2002; Chen and Liang, 2002). Other modes included eco-economic governance (Su et al., 2002), three-dimensional ecological agriculture, migration development, and agroforestry management (Zuo, 2010). A recent report, however, indicated that these modes failed to fundamentally change local ecological, economic, and social conditions and that rocky desertification and rural poverty still restrict the harmonious development of the karst areas in southwest China (Zuo, 2014).

Although many karst management modes were evaluated in China with the aim of clarifying the ecological benefits (Chen et al., 2007a,b; Long et al., 2005; Wu et al., 2009), economic benefits (Li et al., 2010) and sustainability (Deng et al., 2012; Peng and Xiong, 2003), these evaluations have shortcomings. Most of the economic studies have failed to consider ecology, and most of the ecological studies have ignored the economic needs of local populations. Although some environmental–economic methods based on integrated indices of ecology, economy, and society have been used for quantitative evaluation, they have disadvantages. The environmental-economic methods, which quantifies the ecological benefits based on market value, alternative cost, payment invention, and opportunity cost (Yao et al., 2009), is restricted by the subjective opinion of people, the technology level, and the economic development degree etc. Consequently, it fails to objectively evaluate the value of natural resources and the ecological benefits of controlling rocky desertification. Integrated indices include dozens of indicators in different proportions, e.g., forest coverage, soil erosion ratio, rocky desertification degree, grain output, economic forest and grass income, per capita GDP, per capita arable land for economic benefits, total labor capacity, the number of people with junior high school or higher education, and the number of people who are illiterate or semi-illiterate (Deng et al., 2012). These indices seem to be comprehensive but they are difficult to objectively quantify and they fail to determine the true ecological–economic benefits of the control modes (Zhang et al., 2010). Furthermore, the indices that are used differ among researchers, making it difficult to compare the results from different studies (Zuo, 2014). Therefore, a unified method of assessing energy flow, material flow, and money flow is needed to objectively and quantitatively evaluate rocky desertification control modes.

The idea of emergy, which was introduced by H. T. Odum and his colleagues and students in the early 1980s, is defined as one kind of energy previously used directly and indirectly for the production of another kind of energy, material, or service (Odum, 1996). As a biophysical donor-based valuation method, emergy evaluation can access different qualities and types of energies, materials, and information with a common unit, the solar equivalent joule (sej). Some scientists use emergy evaluation to link the environment and economy because it can objectively account for the contributions to a system/process from both the environment and the economy on an equal basis, i.e., in terms of emergy. After over 30 years of development, emergy evaluation has become a mature ecological–economic tool that has been widely used for evaluating many kinds of ecological–economic systems and processes (Campbell and Ohrt, 2009; Lu et al., 2002, 2006; 2010; Tilley and Brown, 2006). Although some previous studies have used emergy evaluation to assess karst provinces (Li and Luo, 2015; Li, 2014; Li et al., 2015; Luo et al., 2012), countries (Dai and Zhou, 2005; Luo et al., 2011a,b), agricultural systems (Han et al., 2010; Yang et al., 2012), and the ecological and economic characteristics of integrated farming-stockbreeding biogas systems in karst areas (Chen and Chen, 2012, 2014; Yang and Chen, 2014), the concept of emergy has not been used to evaluate the ecological–economic benefits of the rocky desertification management modes.

Southwest China has the world's largest contiguous karst areas, and these karst areas experience serious conflicts between human development and ecosystem preservation; Guizhou Province is located in the center of this region (Zuo, 2010). Zhenfeng, Guanling Buyi and Miao Autonomous Counties are typical plateau–canyon karst areas in Guizhou Province. The local people have developed three well-known rocky desertification control modes, i.e., the pepper planting (PP) mode, the honeysuckle-plum inter-planting (HPIP) mode, and the pitaya cultivation (PC) mode (Deng, 2014; Peng et al., 2013). These modes, however, have not been quantitatively evaluated from an integrated ecological and economic perspective. Consequently, it is unclear which of them is better and how they could be optimized. An integrated emergy and economic evaluation of these three typical rocky desertification control modes was done in the current study. The study had the following objectives: (1) to identify which of the three rocky desertification control modes is best; (2) to determine the value of adding ecological engineering subsystems to the PP mode; and (3) to optimize the modes and make recommendations in support of local sustainable development.

2. Materials and methods

2.1. Study area description

The PP mode was studied in Yindongwan Village (25°37′17″–25°40′10″N, 105°39′27″-105°41′25″E), Beipanjiang Town, Zhenfeng County. The PC mode was studied in Xiagu Village (25°40′15″–25°42′13″N, 105°36′45″–105°40′2″E), Guanling Buyi and Miao Autonomous County. These two study sites are divided by the Huajiang River and located in opposite, and both of them are extremely developed karst area. The area receives an annual average solar radiation of 4.17E + 09 J/m^2 and an annual average rainfall of 1100 mm, which occurs mainly from May to October. The annual average temperature is 18.4 °C. This area has a south subtropical dry and hot valley climate with a warm–dry winter and spring, and a hot–wet summer and autumn. The elevation ranges from 500 to 1200 m.

The HPIP mode was studied in Niuping Village, Min'gu Town, Zhenfeng County (25°21′29″–25°24′55″N, 105°39′46″–105°41′43″E). This area receives an annual average solar radiation of 4.17E + 09 J/m^2; the annual average rainfall is 1412 mm, and the annual average temperature is 16.4 °C. The area has a mountain microclimate without cold winters or hot summers. Its average elevation is about 1500 m.

Corn planting (CP) was also studied as an experimental control. CP was developed in the area before ecological approaches to rocky desertification control (such as PP, PC, and HPIP) were developed. CP was studied in Maomaozhai Village, northeast of Beipanjiang Town, Zhenfeng County (25°36′23″–25°38′53″N, 105°36′19″–105°39′2″E). This area has an annual average solar radiation of 4.17E + 09 J/m^2 and an annual average rainfall of 1400 mm. The area has a perennial mild climate without cold winters or hot summers. The location of each of the four study sites is indicated in Fig. 1.

2.2. Description of the desertification control modes

2.2.1. The pepper planting (PP) mode

In the PP mode, farmers cultivate Chinese pepper (*Zanthoxylum bungeanum* Maxim), which is a small tree or shrub, in the rocky desertification areas without altering the primitive topography. The mode was developed in 1992 and is locally referred to as the

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